JUAS Vacuum Lectures & Tutorials Correction Examination – 14-15 March 2017

For questions 2, 3, 4 and 5, give explicitly and develop step by step the analytical formulas used for the computations.

The total points for the examination is 25, letting you the possibility to choose the exercise with which you feel more comfortable in order to obtain the highest mark.

1. Give the correct answer (there might be several good answers) – 6 points

a) The ultimate vacuum pressure in a system is dominated by:

a. ~~The amount of molecules initially present in the volume~~

b. The cleanliness of the vacuum chamber walls

c. The temperature of the vacuum vessel

b) For a gas density of 10^9 molecules/cm^3 at room temperature, 300 K, the pressure equals:

a. ~~4 10-12 Pa~~

b. ~~760 Torr~~

c. 3 10^{-8} Torr

c) For a gas density of 10^{15} molecules/m^3 at room temperature, 3 K, the pressure equals:

a. ~~4 10-14 Pa~~

b. ~~0.76 Torr~~

c. 3 10^{-10} Torr

d) The pressure is:

a. ~~due to the stress before the exam~~

b. proportional to the gas density

c. defined as the force per unit of area

e) The typical energy of chemisorption is:

a. in the range of 1 eV

b. ~~in the range of 0.1 eV~~

c. in the range of 100 kJ/mole

f) A residual gas analysis of an unbaked vacuum system will show a spectrum dominated by:

a. water

b. ~~hydrogen~~

c. ~~helium~~

2. Hot filament ionisation gauge – 2 points

Describe the operating principle of a Bayard-Alpert gauge. Which effect are limiting the reading at low pressure?

Keywords are: electron filament, molecule ionisation, ion collector, outgassing, X-ray limit

3. Desorption of a monolayer of gas – 2 points

Assume a 1 m long vacuum chamber of 10 cm inner diameter onto which a monolayer of gas is adsorbed (10^{15} molecule/cm^2). The vacuum system is closed without external pumping, what would be the final pressure if the monolayer of gas is desorbed into the volume held at 300 K?

Surface, A, of the vacuum vessel:

$$A = \pi DL + 2\,\pi \frac{D^2}{4} = 3298.7\ cm^2$$

Number, N, of molecules on the surface:

$$N = \ A\, 10^{15} \ = 3.3\ 10^{18}\ molecules$$

Volume, V, of the vacuum vessel:

$$V = L\,\pi \frac{D^2}{4} = 7.85\ 10^{-3}\ m^3$$

Gas density, n:

$$n = \frac{\mathrm{N}}{V} = 4\ 10^{20}\ molecules\ m^{-3}$$

Corresponding pressure at 300K, P:

$$P = n\ k\ T = 1.7\ \ Pa$$

A monolayer of adsorbed onto a surface corresponds to a high pressure level !

4. A vacuum chamber connected to a turbo-molecular pump – 5 points

a) Consider a Cu baked vacuum chamber of 5 cm inner diameter and length 4 m. What is the main gas? What is its total outgassing rate?

The main gas is hydrogen. For copper, the specific outgassing rate, q, is 10^{-12} Torr.l.s^{-1}.cm^{-2}.

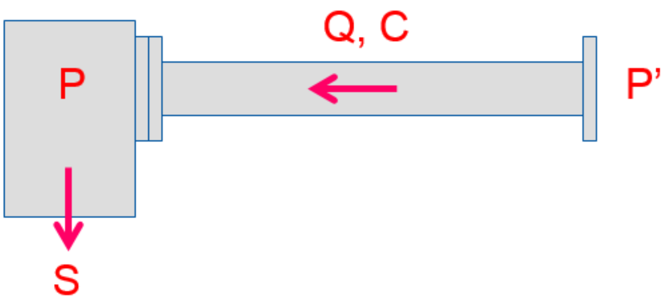
The surface of the vacuum vessel equals:

$$A = \pi DL + 2\ \pi \frac{D^2}{4}\ = 6322.5\ cm^2$$

Thus, the total outgassing rate, Q, equals:

$$Q = q\ A = 6.3\ 10^{-9}\ \ Torr.l.s^{-1}$$

b) As shown in the sketch below, this vacuum chamber is connected to a Pfeiffer turbomolecular pump HiPace 80 DN63 (see data sheet). What is its pumping speed, S? What is the pressure, P, reached at the level of the pump?



The pumping speed, S, for hydrogen equals 48 l/s.

The pressure, P, at the level of the pump is given by:

$$P = \frac{Q}{S} = 1.3\ 10^{-10}\ \ Torr$$

c) What is the conductance of the tube, C, for hydrogen? What is the pressure P' reached at the tube extremity.

The conductance for a tube, C, for a molar mass , M, at temperature, T, is given by:

$$C = 12.1\ \frac{D^3}{L}\sqrt{\frac{T}{M}} = 14.4\ \ l.s^{-1}$$

The pressure, P', is given by the definition of the conductance

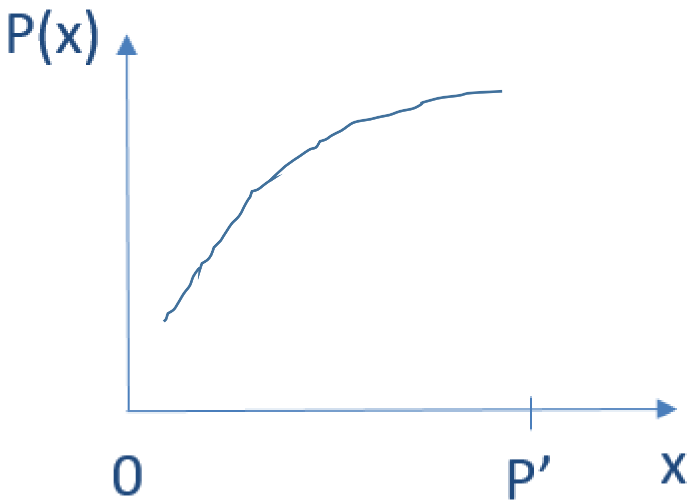
$$P' = \frac{Q}{C} + P = 5.7\ 10^{-10}\ \ Torr$$

d) Write down the effective pumping speed seen from the pressure gauge located in P', what is its value?

The pressure, P', is given by the effective pumping speed which is the conductance in serie with a pumps. The effective pumping speed equals

$$S_{eff} = \frac{S\ C}{S + C} = 11\ \ l.s^{-1}$$

e) Draw the pressure profile along the tube, what is the shape of the profile? The pump is placed at x=0.



The profile is parabolic with a minimum of 1.3 10^{-10} Torr at x=0 and a maximum of 5.7 10^{-10} Torr at x=P'

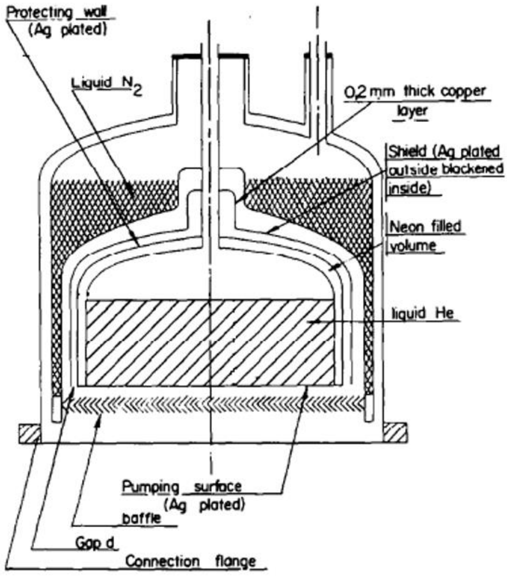
f) Your boss would like to reduce further the pressure in the vacuum system, to do so, he proposes to replace the HP80 turbomolecular pump which cost 1.5 kCHF by a large one, HP300 which has a pumping speed for hydrogen of 220 l/s for a price of 2.5 kCHF. Would you follow his recommendation? Why?

With the new pump of 220 l/s, the effective pumping speed would be 13.5 l/s, so a pumping speed gain of 22% for a price increase of 67 %! This is not a good investment, so the recommendation shall not be followed.

Bearing	Hybrid
Compression ratio for Ar	> 1 · 10^{11}
Compression ratio for H_2	1.4 · 10^{6}
Compression ratio for He	1.3 · 10^{8}
Compression ratio for N_2	> 1 · 10^{11}
Cooling method, optional	Air/Water
Cooling method, standard	Convection
Cooling water consumption	75 l/h
Cooling water temperature	5-25 °C
Electronic drive unit	with TC 110
Flange (in)	DN 63 CF-F
Flange (out)	DN 16 ISO-KF / G 1/4"
Fore-vacuum max. for N_2	22 hPa | 16.5 Torr | 22 mbar
Gas throughput at full rotational speed for Ar	0.54 hPa l/s | 0.41 Torr l/s | 0.54 mbar l/s
Gas throughput at full rotational speed for H_2	15.3 hPa l/s | 11.47 Torr l/s | 15.3 mbar l/s
Gas throughput at full rotational speed for He	2.7 hPa l/s | 2.02 Torr l/s | 2.7 mbar l/s
Gas throughput at full rotational speed for N_2	1.3 hPa l/s | 0.97 Torr l/s | 1.3 mbar l/s
Interfaces	RS-485, Remote
Mounting orientation	in any orientation
Operating voltage	24 (± 5 %) V DC
Permissible magnetic field max.	3.3 mT
Protection category	IP54
Pumping speed for Ar	66 l/s
Pumping speed for H_2	48 l/s
Pumping speed for He	58 l/s
Pumping speed for N_2	67 l/s
Rotation speed ± 2 %	90,000 rpm | 90,000 min^{-1}
Rotation speed variable	50 - 100 %
Run-up time	1.7 min
Ultimate pressure according to PNEUROP	< 5 · 10^{-10} hPa | < 3.75 · 10^{-10} Torr | < 5 · 10^{-10} mbar
Venting connection	G 1/8"
Weight	3.8 kg | 8.38 lb

5. A condensation cryopump – 5 points

A XHV condensation cryopump which operates at 2.3 K is shown in the picture below:



C. Benvenuti *et al.* Vacuum, 29, 11-12, (1974) 591

a) The cold surface is a disk of diameter 62 cm. What is the ideal pumping speed (*i.e.* for a sticking coefficient = 1) of H_2 at 300 K?

The ideal pumping speed, S, is given by:

$$S = 3.63\, A \sqrt{\frac{T}{M}}$$

With A the area of the cold surface in cm^2, T, the temperature (kinetic energy) of the molecule, and M, its molar mass. The molecules being at 300K, with M=2

$$A = \pi \frac{D^2}{4} = 3019\ cm^2$$

So,

$$S = 134\ 223\ ls^{-1}$$

b) A baffle, of chevron type, with a molecular transmission α is placed in front of the pumping surface. The baffle conductance for H_2 at 300 K equals 36240 l/s. What is the molecular transmission (*i.e.* the ratio of the conductance to the ideal pumping speed)?

$$\alpha = \frac{c}{S} = 0.27$$

c) The measured pumping speed of the condensation cryopump is 27 000 l/s, what is the capture factor?

The capture factor, C_f, is defined by the ration of the pumping speed of the cryopump, S_p, to the ideal pumping speed, S:

$$C_f = \frac{S_p}{S} = 0.20$$

d) What is the hydrogen sticking coefficient and the pumping speed of the cold surface?

The capture factor is the “effective pumping speed” of the cryopump which is defined by the molecular transmission in series with the srikcing coefficient, σ:

$$\frac{1}{C_f} = \frac{1}{\alpha} + \frac{1}{\sigma} <=> \sigma = \frac{\alpha\, C_f}{\alpha - C_f} = 0.79$$

e) A hydrogen gas flux of 2.7 10^{-8} mbar.l/s is injected into the condensation cryopump. What is the equilibrium pressure?

The equilibrium pressure, P, is given by:

$$P = \frac{Q}{\sigma S} = 1\ 10^{-12}\ \ mbar$$

f) The pump operated at the same constant gas flux during 300 days, what is the total gas load during that period? What is the equilibrium pressure at 2.3 K? What do you conclude?

The gas load is given by:

$$\int Q\ dt = 0.7\ \ mbar.l <=> 3\ 10^{19}\, molecules$$

The corresponding coverage, θ, equals:

$$\theta = \frac{\int Qdt}{A} = 10^{16}\ \ H_2.cm^2$$

This correspond to several monolayers of gas, for which the saturated vapour pressure equals a few 10^{-11} mbar. The cryopump must be regenerated to recover the operating pressure.

6. Photon stimulated molecular gas desorption in a lumped pumping system – 5 points

In a 3 GeV synchrotron radiation (SR) source, a baked Cu vacuum chamber of 10 cm diameter, placed downstream to bending magnet, is irradiated by synchrotron radiation with 3.75 keV critical energy.

a) Write down the formula of critical energy, what does the critical energy means?

The critical energy is given by:

$$\varepsilon_c = \frac{3}{2}\frac{hc}{2\pi}\frac{\gamma^3}{\rho}$$

It corresponds to the energy at which the synchrotron radiation power spectrum is halved in 2 equal parts.

b) Write down the formula to compute the linear photon flux for an electron beam (number of photons emitted per meter of trajectory per second). Compute the linear photon flux when a beam current of 100 mA circulates in the ring.

$$\dot{\Gamma} = \frac{5\sqrt{3}}{12h}\frac{e}{\varepsilon_c c}\frac{\gamma}{\rho} I = 1.288\ 10^{17}\ \frac{E}{\rho}\ I$$

The bending radius can be obtained from the critical energy formula

$$\rho = \frac{3}{2}\frac{hc}{2\pi}\frac{\gamma^3}{\varepsilon_c} = 2.218\ \frac{3^3}{3.75} = 15.97\ m$$

Therefore, the linear photon flux equals:

$$\dot{\Gamma} = 1.288\ 10^{17}\ \frac{3}{15.97}\ 100 = 2.4\ 10^{18}\ ph.m^{-1}.s^{-1}$$

c) Compute the integrated photon dose after 12h of continuous irradiation. What are the typical desorption yield of H_2 at that photon dose (see graph lecture 4, p28)?

The integrated photon dose, Γ, is given by:

$$\Gamma = \int \dot{\Gamma}\ dt = 1\ 10^{23}\ ph.m^{-1}$$

At this dose, the desorption yield equals ~ 3 10^{-5} H_2/ph.

d) After 12h of irradiation, what is the gas load due to PSD? Express the PSD gas load in unit of mbar.l/s/m

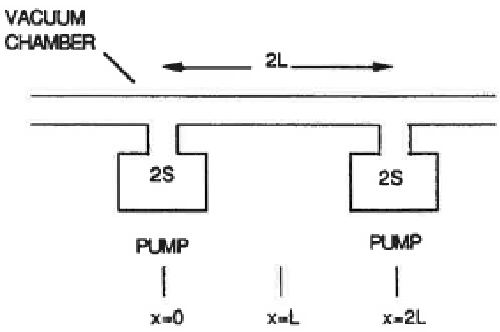
The gas load, Q, is given by:

$$Q = \eta\dot{\Gamma} = 7.3\ 10^{13}\ H_2.m^{-1}.s^{-1}$$

The conversion factor, G, from molecule to mbar.l, can be obtained from the ideal gas law. It is given in lecture 2, slide 6. So

$$Q = \eta\dot{\Gamma} = 7.3\ 10^{13}\ H_2.m^{-1}.s^{-1} <=> 1.7\ 10^{-6}\ mbar.l.m^{-1}.s^{-1}$$

e) The Cu vacuum chamber is part of a “simple machine” where 300 l/s pumps, 2S, are placed every 28 m, 2L, (see lecture 5, p 13). Write down the specific conductance of the tube, c, the gas desorption per unit length, a. Express and compute the average pressure in the simple machine.



The specific conductance, c, is the conductance of a 1 m long tube. It equals:

$$c = 12.1\frac{D^3}{L} = 121\ l.s^{-1}.m$$

The gas desorption per unit length, a, is the gas load, it equals:

$$a = 1.7\ 10^{-6}\ mbar.l.m^{-1}.s^{-1}$$

The average pressure in the simple machine is given by:

$$P_{av} = a\ L\ \left[\frac{1}{S} + \frac{1}{3c}\right] = 1\ 10^{-6}\ mbar$$

f) Assuming the PSD yield scales like η ≈ D^{-1}, what is the hydrogen PSD yield after a conditioning period of 12 000h (500 days)? What is the expected average pressure in the “simple machine”? What do you conclude when comparing with p25, lecture 4?

After a conditioning period of 12 000h (~1.5 years of operation), the accumulated photon dose equals:

$$\Gamma = \int \dot{\Gamma}\ dt = 1\ 10^{26}\ ph.m^{-1}$$

Which is 3 ordered of magnitude larger than after 12h, So, the photodesorption yield is decreased by 3 orders of magnitude. It equals:

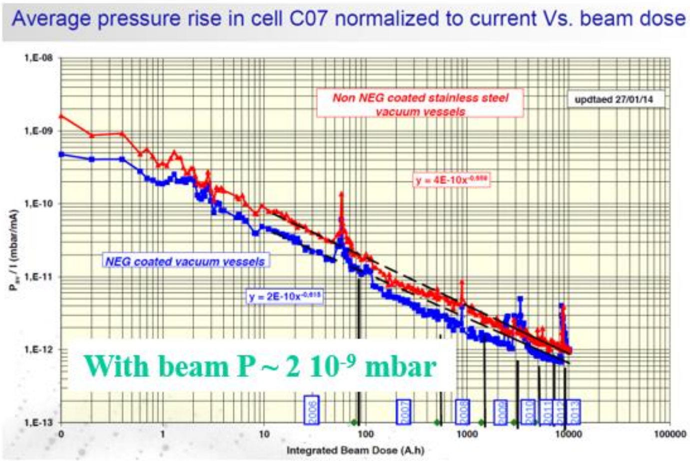
$$\eta = 3\ 10^{-8}\ H_2.ph^{-1}$$

The average pressure should be therefore reduced also by 3 orders of magnitude and reach:

$$P_{av} = 1\ 10^{-9}\ mbar$$

Comparing with p25, lecture 4, this value is comparable with the average pressure obtained in Soleil after ~ 2 000 A.h of operation i.e. 167 days with 500 mA beams. The plot below is therefore consistent with a baked Cu chamber as expected.

SOLEIL



C. Herbeaux, Journée thématiques RTVide, décembre 2014